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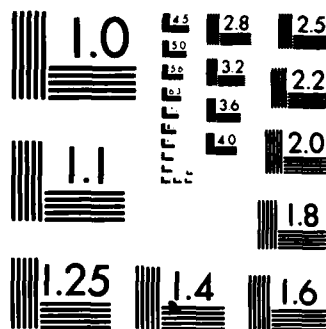              N00014-85-K-0646

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QUARTERLY PROGRESS LETTER

TURBULENT STRUCTURE, MIXING AND COMBUSTION

OFFICE OF NAVAL RESEARCH

Contract No. N00014-85-K-0646

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## Transverse Jets

The main purpose of the studies on transverse jets is to define the mixing processes in transverse jets and their relation to the vortical structure of the jet. Both near field and far field and the relation of the latter to the former are of interest.

As reported previously (30 November, 1984, Quarterly Status Report for Contract No. N00014-76-C-0260), we had discovered that the "wake region" of a transverse jet contains a train of alternating vortices, each one extending from the ground plane (from which the jet issues) to the jet itself. The train has been observed to persist up to a few hundred diameters downstream of the jet. At one end the vortices are attached to the bounding wall of the flow. At the other end they are entrained into the main jet; thus they are being stretched as they convect downstream, since the jet trajectory is increasing its distance from the wall. These observations were made in a water tunnel, using laser induced fluorescence to visualize the structures.

To study the near field of the transverse jet a new apparatus has been constructed. This consists of a jet, 1.5 inches in diameter, discharging into an open-circuit wind tunnel with 20 in square test section. In this setup, smoke wires can be effectively used to visualize various planes of flow either inside or outside the jet. The attached figures show two examples. In figures 1 and 2, the jet is issuing from the upper left-hand corner of the photographs, and the cross flow is from left to right. In figure 1, the smoke-wire is placed upstream and on the center plane of the jet. This visualizes the leading edge of the jet which is seen to be dominated by large-scale organized structures much like those of a two-dimensional shear layer. Locating the smoke-wire upstream and about one diameter off the center plane of the jet reveals vortical filaments extending from the core of the jet upward and slanted toward the right (see Figure 2). We believe that these are the same as the vortical structures which we have previously observed in the far field

of the transverse jet, as described above.


Control of Turbulent Shear Flows


A comprehensive examination of possibilities, techniques and underlying principles for controlling or modifying turbulent flows was undertaken in collaboration with W.C. Reynolds of Stanford University.


Figure 3 is a schematic diagram of the basic flow scenario relevant to control. Each flow (shear layer, wake, etc.) has a primary Instability mode which results in the Large Structure (waves or vortical structures) and determines the Development of the flow (including smaller turbulent structure). The instability may be affected by Forcing, either "naturally" by environmental Noise or "artificially" by Passive of Active Control. Forcing may also occur through Coupling, often called "feedback", between the "point of instability", e.g., a separation point, and the downstream large structure, especially if the latter interacts with a fixed edge or an active control element.


To place into some orderly context the methods that have been used by various investigators to control or modify turbulent shear flows, they were classified into three main groups as follows:


1. Passive Control

    a. by modification of the instability

    b. by interference with the large structures: downstream effects

    c. by interference with the large structures: feedback effects

    d. by modification of the feedback

2. Active Control, Open Loop

    a. by forcing at the point of instability

    b. by forcing at the large structure

    c. by modulation of the feedback

3. Active Control, Closed Loop

a.  by forcing at the point of instability

b.  by forcing active control at the large structure

c.  by modulation of the feedback

Each of these will be discussed and illustrated with examples where available.

This classification was illustrated by examples which were discussed in an invited paper in the Colloquium on Free Shear Flows/Propulsion at the AIAA 24th Aerospace Sciences Meeting (cited below). The written paper was not completed in time for the meeting; we do plan to (improve and) complete it when time permits.

## Effects of Damkohler Number in a Turbulent Shear Layer

Very important for the problem of turbulent combustion, it is important to understand the processes at the level of the interfaces, where interdiffusion of species occurs; in turbulent combustion these are the flame sheets. A relevant parameter here is the Dahmkohler number, $Da$, the ratio of a characteristic flow time to the reaction time.

In this work, a simple model describing chemical reaction in a turbulent shear layer is put in quantitative form and the model predictions compared with experiment. The reactants are not pre-mixed and the flow is two-dimensional. The dependence of the amount of produce in the layer on the Schmidt, Reynolds and Damkohler numbers and on the stoichiometric ratio is exhibited explicitly in the model. The first two parameters appear as the product (Sc Re) and influence that part of the reaction taking place in strained laminar flames. In the limit $ScRe \to \infty$ (for $Sc > 1$ and $Re \gg 1$) the molecular mixing becomes independent of these parameters as it is in classical turbulence theory but the composition and spatial distribution of the molecularly mixed fluid does not resemble those given by such theories. The model predictions are in reasonable agreement with the experimental results for a Damkohler number range from zero to a

mixing limited value. The comparison with a set of data for gases in which Re was varies is somewhat less satisfactory.

## Reports and Publications

A. Roshko and W.C. Reynolds "Modification of Free Shear Flows by Passive Interference". AIAA-86-0236. (Still in preparation, with the more accurate title, "Modification of Free Shear Flows by Passive Interference or Active Excitation").

Lorenz W. Sigurdson "The Structure and Control of a Turbulent Reattaching Flow", Ph.D. Thesis, California Institute of Technology, 1986.

L. Bernal and A. Roshko "Streamwise Vortex Structure in Plane Mixing Layers". Accepted for publication in Journal of Fluid Mechanics.
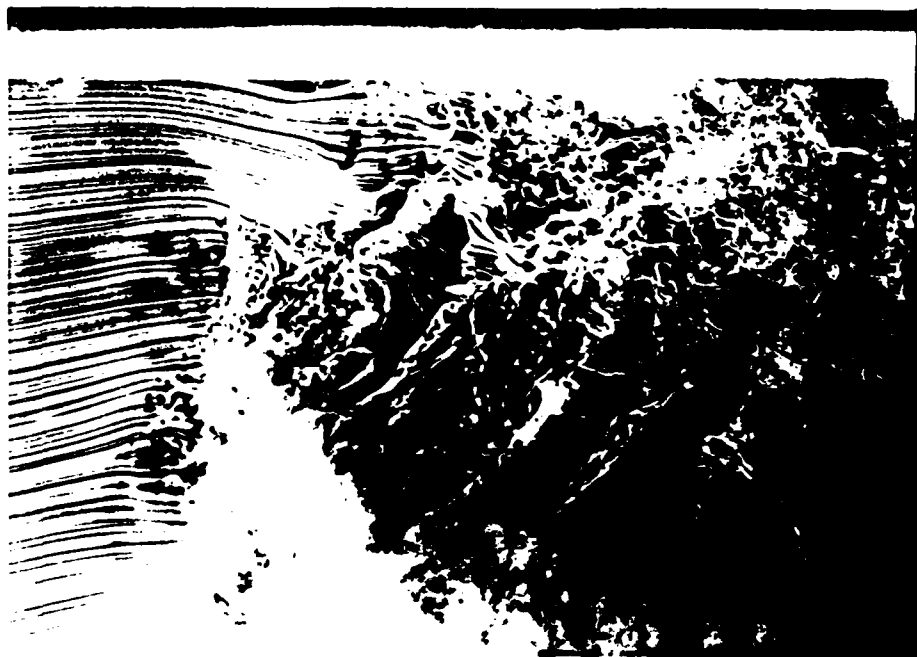
John M. Cimbala, Hassan M. Nagib and Anatol Roshko "Large Structure in the Far Wakes of Two-Dimensional Bluff Bodies". Submitted to Journal of Fluid Mechanics, in review.

J.E. Broadwell and M.G. Mungal "The Effects of Damkohler Number in a Turbulent Shear Layer". GALCIT Report FM86-01, 1986.
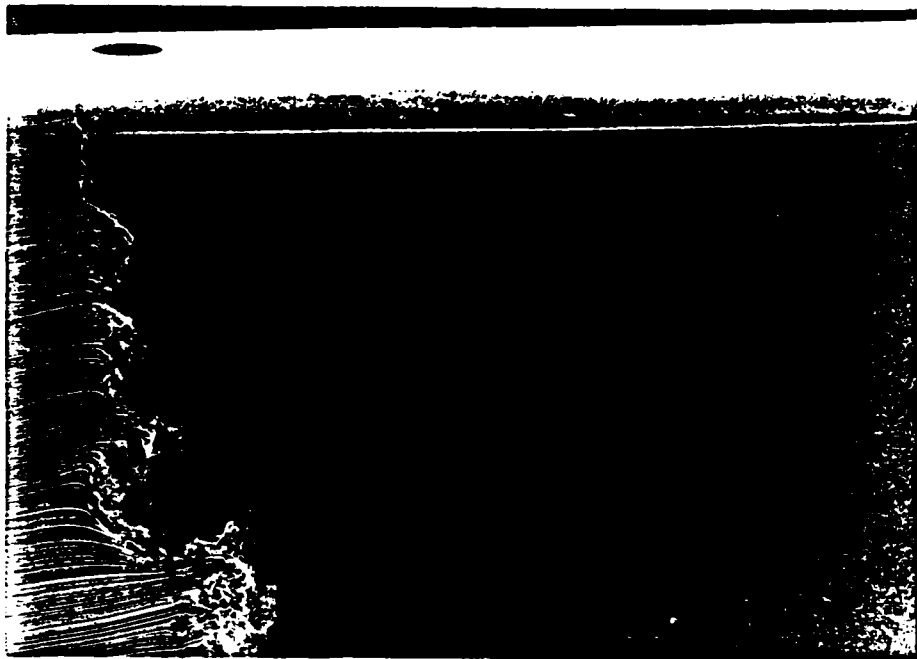
$Re_{jet} = 49,000 \quad VR = u_{jet}/u_{cross\ flow} = 8$
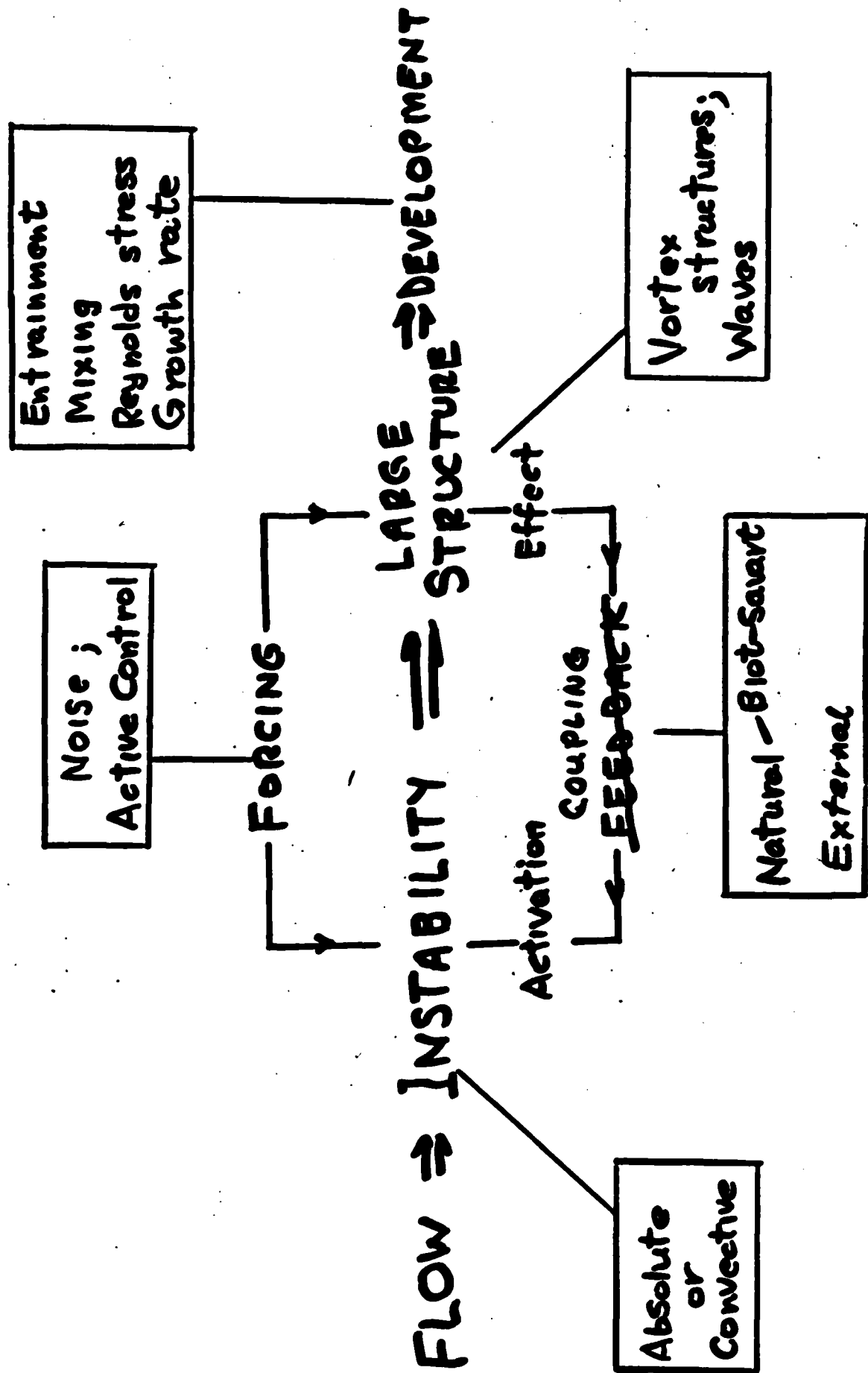
Figure 1



$Re_{jet} = 49,000 \quad VR = 8$

Figure 2

Figure 3. Scenario for Control of Turbulent Shear Flows.

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